PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC
100: 1228–1232, October 1988

A SEARCH FOR THE PERSEUS FLASHER AND THE LIMITS ON OPTICAL BURST RATES*

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Received 1988 April 27, revised 1988 July 11

ABSTRACT

We conducted a study of the error box of the possible optical burster, reported by Katz *et al.* (1986). This "Perseus Flasher" was subsequently identified with satellite glints by Maley (1987), a conclusion with which we fully concur. Our study, completed before Maley's report, involved a search for highly-variable objects on archival and newly-taken plates, with a total integration time of about 260 hours, a proper-motion survey of the area, deep optical imaging with a CCD, and a single-dish radio monitoring. We found no optical or radio bursts or any other unusual objects in this area. Our upper limit to the optical flash rate from the error box of the flash photographed by Katz *et al.* is at least 20 times lower than the flash rate reported by those authors. Similar negative results were achieved independently by other groups; like them, we conclude that the photographed flash was most likely caused by an Earth-orbiting artifact and that most of the remaining, visually-detected flashes were spurious. From our data, we derive limits on the optical flash rates from astrophysically-interesting sources.

Key words: optical bursts–null observation–observational limits

I. Introduction

Gamma-ray bursts are a fascinating and still poorly understood astrophysical phenomenon. Since γ-ray burst astronomy is still in its infancy, and the observations are scarce and expensive, it would be of considerable interest to open an avenue on some more-accessible wavelength in investigating this problem. After the pioneering effort by Grindlay, Wright, and McCrosky (1974), Schaefer (1981) succeeded in finding an apparent optical counterpart of a γ-ray burster. Several other interesting reports appeared in the literature (e.g., Widowiak and Clifton 1985; Pedersen *et al.* 1983, 1984; Schaefer, Seitzer, and Bradt 1983; etc.), but none of them was a clear-cut case. It is, of course, possible that there are nontrivial (e.g., not associated with meteors, known flare stars, etc.) *optical* bursters, which are not associated with γ-ray bursters and

*Based in part on data obtained at Lick Observatory, University of California.

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would represent some interesting, heretofore unknown, astrophysical phenomenon. However, we note that Zytkow (1988) has called into question the alleged astrophysical origin of the optical bursts identified on archival plates.

It was thus that the announcement of a possible optical burster by Katz *et al.* (1986) attracted some attention. These authors reported repeated visual sightings of optical flashes from a locus in Perseus, which did not look like meteoric or satellite flashes; but what gave a serious credibility to their claim was that they photographed one of the flashes (cf. also MacRobert 1985*a,b*). The analysis of this photograph by Katz *et al.* suggested that the flash was stellar and not associated with any obvious terrestrial source. The visual properties (e.g., amplitude, duration) of this and other flashes reported by Katz *et al.* were consistent with those of other optical bursters reported in the literature. The photographed optical burst is also located within three (admitedly large) error boxes of previously cataloged γ-ray bursts. In view of the previous work on optical counterparts of γ-ray bursters, the report by Katz *et al.* was quite plausible. The "Perseus Flasher", as the Katz *et al.* object became known, if confirmed, would be a very important object. Its reported burst frequency (approximately one flash per 12^h for the 0^m–2^m flashes; fainter flashes could well be more frequent) would make it a gratifying target for future studies.

In view of the potential importance of this discovery, we undertook some follow-up observations of the optical error box reported by Katz *et al.* We found no evidence for existence of a frequent optical burster or other unusual astrophysical source at this location of near it. Similar negative results were reported by Schaefer *et al.* (1987*b* and references therein), Halliday, Feldman, and Blackwell (1987), Corso, Ringwald, and Harris (1987), and Lewin *et al.* (1987). Maley (1987) proposed a definite identification of the photographed flash as being a satellite reflection glint from the Soviet intelligence craft *Kosmos* 1400. Most other authors, and ourselves, now agree with this interpretation. For the record, we wish to describe our search and the resulting upper limits on the optical flashes of astrophysical interest.

II. The Observations

Schaefer (1981) demonstrated that the plate archives of Harvard College Observatory provide a rich database for searches of relatively bright sporadic events over long time scales. We undertook a limited archival search of this plate material, centered on the error box of the optical flash photographed by Katz *et al.* (1986). The area searched by us initially had dimensions of approximately 11.2 by 15 arc min, in NS and EW, respectively (in order to be sure that the error box reported by Katz *et al.* was fully covered), but as our confidence in their quoted positional errors increased, it was subsequently decreased to 1.9 by 3.9 arc min. However, we generally searched a wider area on most plates, and for our analysis we will assume 1.5×10^{-5} sr as a conservative estimate.

We first searched relatively recent plates, obtained with the Damon cameras at the Oak Ridge Observatory. These are refractive cameras with a primary lens diameter of 4.16 cm and plate scale of 580 arc sec mm^{-1}. Some of the plates were taken in the blue (IIa-O emulsion with a GG13 filter, giving a bandpass 1100 Å wide, centered at 4330 Å), some in the yellow (IIa-D emulsion with the GG11 filter, giving a bandpass 1200 Å wide, centered on 5750 Å), or red (103a-F emulsion with a filter close to RG1, giving a bandpass 850 Å wide, centered on 6560 Å). About one-fifth of the plates were taken in the blue bandpass, while the remainder were a mixture of yellow and red. A 120-minute exposure reaches limiting magnitudes of 15.9, 15.5, and 15.0 for the three bands, respectively. The actual exposure times varied and were typically 30–40 minutes, corresponding to the typical limiting magnitudes of $\sim$ 13. We examined 98 Damon plates, taken between October 1969 and January 1986, with a total integration of 96.1 hours.

No convincing optical bursts were detected on the plates. Two of the plates (Nos. 4581 and 5085) were taken within a few hours of optical flashes reported by Katz *et al.*, viz., those recorded on UT 1985 February 21 and UT 1986 January 11, but again, the results were negative.

We then examined 68 plates from an older patrol series, the RH, taken with the 7.6-cm Ross camera between 1939 and 1951. The RH series plates are known to be among the best in the Harvard archives. There is no record of emulsion or filter, but it is believed that the effective bandpass was blue. The plates have a typical limiting magnitude of 15 or fainter and a plate scale of 391.2 arc sec mm^{-1}. The exposure times varied from 43 to 150 minutes, and the total integration for the plates examined was 97.4 hours. Again, no flashes were found.

Since it was at that time deemed possible that the Flasher is a genuinely new phenomenon on the sky, we also obtained additional, new plate material specifically for this search. The first set of these was taken with the 16-in (40-cm) telescope (MC, for the Metcalf Doublet camera) at the Oak Ridge Observatory. The plate scale is 98.2 arc sec mm^{-1} and limiting magnitude about 17. Nineteen usable plates were taken, ten in the blue (H_2 hypersensitized IIa-O emulsion) and nine in the red (103a-F emulsion with a red filter). The observations were made from October 1985 through March 1986. In order to guard against spurious detections, the following scheme was used: A plate was exposed in a stable pointing; then the telescope was moved a few arc sec and another equal exposure was taken. In this way short events (optical flashes) would appear single, whereas all other stars would appear double. Typical exposure times at each pointing ranged from 14 to 31 minutes, and the total integration with the MC plates was 14.6 hours. Again, no convincing optical bursts were found.

We also obtained 30 plates at the 61-in (1.5-m) reflector at the USNO Flagstaff Station, from UT 1985 December 7 to UT 1986 January 10. All but two plates had exposures of 60 minutes with the total integration time of 29.8 hours. The emulsion was sensitized 103a-F, with an OG550 filter, and the plate scale was 13.55 arc sec mm^{-1}. The limiting visual magnitude was ~ 19. We searched an area of about 30 by 40 arc min. No conspicuous optical flashes were detected, even though a previously-unknown 14^m variable was found near the Flasher error box.

If the flashes were of an extra-solar-system origin, it would be reasonable to suppose that they are from a relatively nearby, probably compact stellar object. One possible signature of such source would be a large proper motion. With this possibility in mind, we conducted a proper-motion survey in the area, using the plates obtained for the Lick northern proper-motion program (Shane and Wirtanen 1967; Klemola, Jones, and Hanson 1987). Fortunately, the error box of the event photographed by Katz *et al.* lies in the corners of four overlapping program fields, involving a total of eleven exposures (blue only or simultaneous blue and yellow) taken over the period 1947 to 1978. The standard exposures were 120 minutes for all but one plate (cut short by clouds to 17 minutes). Only the blue plates (103a-O emulsion) were used in this search, which was conducted in two phases.

We first examined a *small region*, centered on the coordinates of the burst photographed by Katz *et al.*, down to the plate limit at $B \simeq 19$. A conservative estimate of the searched area is 0.4 square degree. No significantly variable or fast-moving objects were detected inside the nominal Flasher error box as given by Katz *et al.*, at a variability level over 0.5–1 mag, and proper motion larger than 0.1 arc sec $year^{-1}$. Just outside this error box, a variable star ($\sim 17^m$–19^m) and two proper-motion stars (0.2 and 2.0 arc sec yr^{-1}) were found but appear unexceptional in the present context. We then examined the *larger area* (about 10° by 11°), searching for brighter (nominally 12^m–13^m, but to a less thorough degree fainter) objects with exceptionally large proper motions; none were found. In both surveys we detected some previously-uncataloged variable stars and large proper-motion stars, all of which were well within normal limits for this part of the sky and none of which appeared unusual in any way.

In order to check for the presence of any faint images of unusual appearance or any faint nebulosity in the area, we obtained deep drift-scan CCD images of a 4 by 10 arc-min field centered on the position of the photographed event. The CCD images were obtained with a TI No. 2 CCD at the prime focus of the KPNO 4-m telescope on UT 1985 December 15. The images are 800 by 2000 pixels, with the pixel scale 0.297 arc sec, and exposure times of 67 and 600 sec per pixel. Both images were obtained in the R band, which also includes the Hα emission line, under excellent photometric and seeing conditions. The limiting magnitude of the deeper image is about 24 (red). In addition, several CCD images of lower quality were obtained earlier at the Lick 3-m telescope. No objects with either unusual features or morphology or any faint nebulosities were found.

In an attempt to see if radio bursts were accompanying the optical bursts, we observed this direction with the 85-foot radio telescope at Hat Creek, California. The observations were conducted at 1420 MHz. At this frequency the beamwidth of the telescope is 36 arc min which is considerably larger than the positional uncertainty of the flasher reported by Katz *et al.* (1986). A 40-MHz signal centered at 1420 MHz was broken up into four bands of 20 MHz and two senses of polarization. These four bands were detected by means of a digital square-law detector (a three-level digital correlator) and sampled every second. With a system temperature of better than 50 K, the effective rms detected in any band is 10 mJy per 1 second of integration.

A total of 12 hours of data (2×6 hours) was obtained in the manner described above. A visual display of all four signals showed that there were no obvious interference signals in our data. Averaging the four bands allows us to put limits of 15 mJy for a burst ($3\,\sigma$ limit) of mean duration of 1 second. We then increased the effective integration time of each of the four detected signals (by simply adding n neighboring points) in order to look for bursts with duration of n seconds. No bursts were found that were correlated over burst time scales of $n = 2$ and $n = 5$ seconds to 15 mJy/$\sqrt{n}$. Thus, we conclude that, at least over the 12 hours of our observations, there were no radio flares to the level of sensitivity described above from the flasher direction.

III. Discussion

We have thus surveyed relatively deep photographs of the area with the total integration time of approximately 260 hours, and no optical flashes were seen. The limiting magnitudes for short (subsecond) flashes are difficult to estimate because of the inherent nonlinearity of reciprocity failure in photographic plates. The limiting flash magnitude would depend on when during the exposure did a tentative flash occur, how long it was, what was its light curve, how was the plate hypersensitized, whether the sky level was above the plate fog, etc. A simple order-of-magnitude estimate is to assume a "one-second uniform" flash and subtract 2.5 log (t_{exp} sec^{-1}) from the limiting magnitude of a plate (the reciprocity failure decreases the implied sensitivity somewhat, but that effect is hard to quantify). If we do so, we find that we would have detected an $\sim 5^m$ one-second-equivalent flash on *any* of the plates examined, and in most cases we would have detected flashes a couple of magnitudes fainter. This is, then, in clear contradiction with the optical flash rate reported by Katz *et al.* by a factor of 20 or so, and we must conclude that most of their visual flash sightings were spurious.

Our detection limits on the flash rate are summarized in Figure 1 along with the limits taken from Schaefer *et al.* (1984, 1987*a*). The Perseus Flasher rate was computed by using the estimated rate from Katz *et al.* (1986) and the area of their photographed event error box; there is some freedom here: One could use the area of a seeing disk or a several-degree locus from their visual sightings. We also plot the prediction for optical flashes from γ-ray bursters, as estimated by Schaefer (1985), which is based on a simple extrapolation from the few known cases. Our flash-rate limits are thus probably not a strong constraint on the optical counterparts of genuine γ-ray bursters but are comparable with some other relevant work in the literature.

Similar negative results were reported independently by Hudec (1987) and Zytkova (in preparation), as reported by Vanderspek, Zachary, and Ricker 1987), who each examined archival Harvard plates with the total integration time of over 1000 hours; Schaefer *et al.* (1987*b*), who monitored the Flasher error box for some 482 hours; Corso *et al.* (1987), who reported on 76 hours' worth of data; and several other groups, as summarized by Schaefer *et al.* (1987*b*). There is thus overwhelming evidence that the optical-flash frequency from the area covered by, and surrounding, the error box of the flash photographed by Katz *et al.* is at least two orders of magnitude smaller than the rate inferred from their visual sightings. The combined upper limits on the optical flash rates are indicated in Figure 1. In addition, the X-ray search by Lewin *et al.* (1987), as well as our deep imaging, proper-motion, and radio studies, did not yield a single interesting object in this area.

We are then left with explaining the flash photographed by Katz *et al.* It was independently suggested from several sources (MacRobert, private communication; Maley 1987; Schaefer *et al.* 1987*b*) that this event was caused by a reflection or a deliberate light signal from a high-orbit artificial satellite; in particular, one of the Soviet *Kosmos* satellites was suggested as a possible culprit. There is no shortage of small artifacts in the geostationary and subgeostationary orbits, and any number of them can be a cause of nonrecursive optical flashes caused, e.g., by a tumbling and reflection of sunlight, collisions, or reentry burning (Schaefer 1985; Shara and Johnston 1986; Maley 1987; Schaefer *et al.* 1987*b*). There also can be head-on meteors with appearances which could deceive even the experienced meteor observers.

The totality of the available data by us and other groups thus suggests that the Perseus Flasher was a "false alarm". But we would like to conclude with a more encouraging note: There really *was* a potential for an exciting discovery

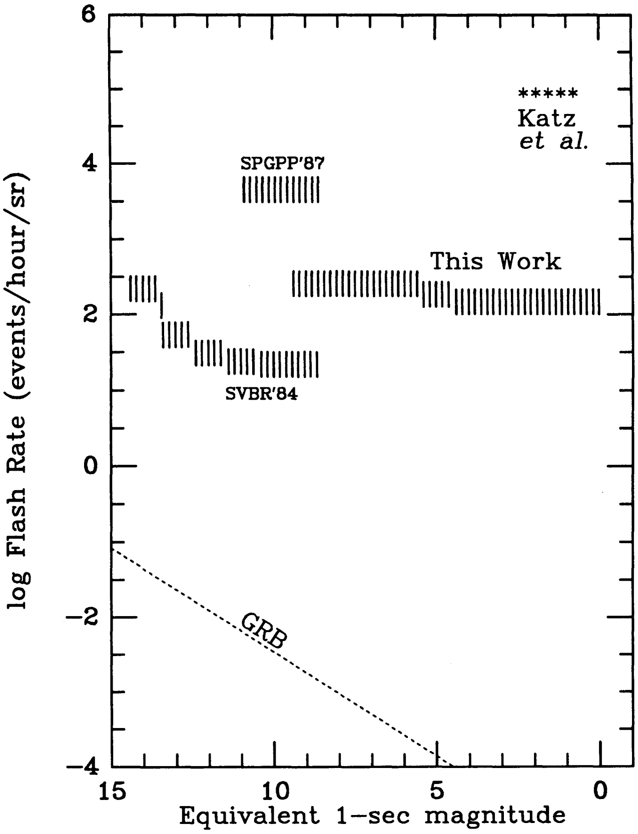

FIG. 1—Upper limits on the optical flash rates as a function of brightness (the 1-sec equivalent magnitude is defined in the text) from this work and the experiments by Schaefer *et al.* (1984, 1987*a*). The estimated rate from the Perseus Flasher reported by Katz *et al.* (1986) is shown as asterisks. The dotted line is an estimate for the optical flash rates from the possible γ-ray bursters, taken from Schaefer (1985), shown here for comparison.

there, and it is possible that in the future another amateur report may lead to a real optical burster or some other interesting phenomenon. There are portions of the observable parameter space where our vigilant amateur colleagues can still make an important contribution, and such efforts are quite worthwhile.

We would like to thank Chen-Yuan Shao for obtaining most of the MC plates at Oak Ridge and Carl Heiles for obtaining the radio data. Hat Creek Observatory is operated by the Department of Astronomy, University of California, Berkeley. We also acknowledge stimulating conversations with Alan MacRobert and Brad Schaefer. We acknowledge partial support from Harvard University (S.D.), California Institute of Technology (S.R.K. and S.D.), and NSF grant AST 84-14142 (A.R.K.).

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